Tim Adlam

Using shape memory alloys

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alloy
smart materials
solenoid
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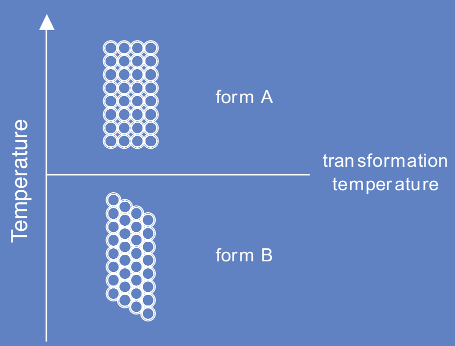
Today, many more people with physical and mental disabilities are leading independent lives at home, thanks in part to recent technological developments. Here, Tim Adlam of the University of Bath describes one project which makes use of smart materials to help people with dementia.

Human muscles can contract and exert large forces with very fine control, but the trouble is they need warmth, blood, nerves and a skeleton made of bone if they are to function consistently and usefully. At the moment engineers can't use biological muscles in their creations except in very unusual circumstances. It would be useful though, if we could employ actuators that work like a muscle – actuators that are compact, powerful and very reliable.

Fortunately there are such actuators – shape memory alloys (SMAs). These are metals that can radically change and recover their shape. They are used in diverse applications from moving the control surfaces of model aircraft to the activation of tiny cages and baskets that are inserted via the arteries deep inside the human body. Box 1 explains how they work.

BOX 1 What is a Shape Memory Alloy?

SMAs are used either where a device needs to change shape, or where a force needs to be applied. They do this when they are heated above a specific transition temperature that varies from alloy to alloy. When they reach this temperature, the internal crystal structure of the metal changes suddenly and the metal shrinks by as much as 5%, at least ten times as much change in length as would normally be expected from a metal that is being heated. As the metal contracts, it exerts a large force. The SMA changes from its ductile annealed state or phase, to a super-elastic phase that is smaller and can tolerate huge amounts of bending and stretching.



Have you seen the glasses frames that you can tie in a knot without damaging them? They are made from an SMA in its super-elastic phase. While the alloy is maintained above its transition temperature, it stays super-elastic and contracted, but if it is allowed to cool below its transition temperature, it becomes possible to stretch it out to its original length with very little force. The problem here is that if it is stretched too much, it loses some of its shape memory and does not contract as well next time it is heated. The alloy can be over-extended. This means that whatever mechanism it is built into must protect it from being over-extended and damaged.

Putting SMAs to work

My own experience of using shape memory alloys has been while designing smart household equipment for people with dementia. At the Bath Institute of Medical Engineering, we have been working with people with dementia since 1999, and the focus of our work has been to develop technology that will support people with dementia in their own homes, enabling them to be more independent, and hopefully postponing the day when they must be admitted to residential care.

One of the problems we set out to solve was how to enable a person with dementia to cook safely when they might often forget to light the gas or to turn it off after use. With my electronics engineer colleague, I designed a cooker monitor that could detect gas or smoke, and then turn off the cooker knobs. If the problem didn't go away, the monitor would then call for help using a GSM mobile phone module to send a text message to a nearby carer. The clever thing about the cooker monitor was the knobs. They could be fitted to just about any cooker in place of the normal knobs and were able to turn off automatically without preventing the person with dementia from using the cooker after the problem had been sorted out.

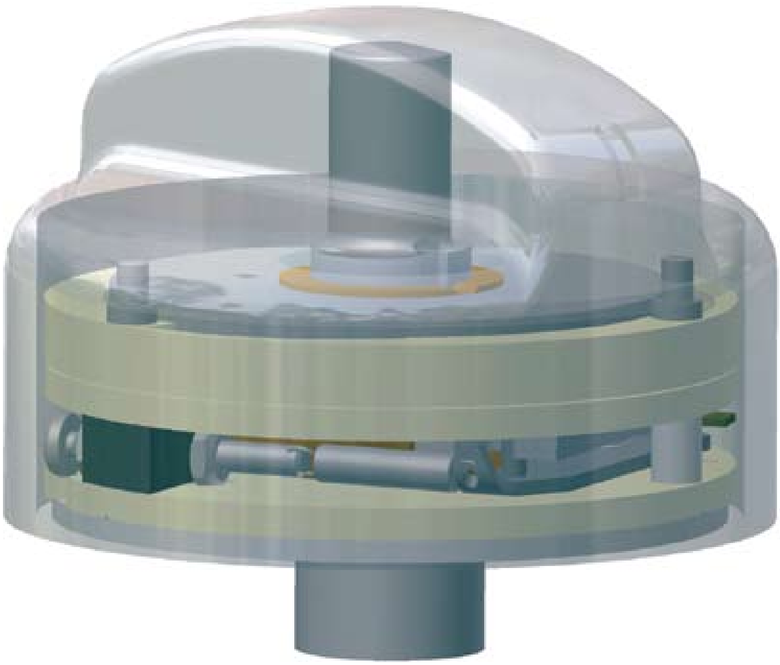
The knobs needed to look just like normal cooker knobs so that they would be recognisable by a person with dementia, but they had to be powerful enough to turn off the gas valve that the normal knobs were attached to. Fitting a mechanism inside each knob that could be relied on to turn off the cooker when needed was a challenge. First we decided to use the user's own strength to turn off the valve by storing the energy they used to turn the valve on in a spring. All we had to do then to turn off the valve was release the energy stored in the spring, and for this we needed to release a ratchet that prevented the spring from unwinding.

Two methods of releasing the ratchet were tried. The first, a compact solenoid could not be built small enough to fit inside a knob and still remain powerful enough to disengage the ratchet; so shape memory alloys were investigated. For this application, it was decided to use a simple wire that could pull the pawl out of the ratchet and release the energy stored in the spring, turning off the knob. The wire had to pull with about 9 N of force and give 1.23 mm of pull.

We chose a straight length of Flexinol alloy. We decided to heat the wire using electricity and its own resistance. The wire has a resistance of a few ohms per metre, and is well suited to electrical heating. We found that a 0.5 mm diameter wire, 25 mm long, gave us 10 N of force and a pull of 1.25 mm.

People with dementia often have problems with memory, attention, judgement and problem-solving.

Two modified cooker knobs; to the user, they look normal.



This view of a modified cooker knob reveals the inner mechanism.

Test rig

We wanted to test the wire and find out exactly what it was capable of. How long would it carry on pulling with 10 N? How reliable was it? How well would it tolerate over-extension, would it be overheated?

To answer these questions, we built a testing rig and set it in the lab to run over a weekend, heating it every few seconds so that it contracted, and then allowing it to cool and be extended again. We didn't protect the wire from over-extension for this experiment as we wanted to see how this would affect it. The results of our experiment are shown in Figure 1. You can clearly see the change in the pull length of the wire as time goes by and it is progressively damaged by the over-extension. It was important for us to protect the wire in the mechanism we designed.

The SMA wire test rig.

Another big problem with using SMAs is that they are very difficult to join to anything. They can't be welded; they are very difficult to machine; they can't be bonded with adhesives; and they can't be soldered or brazed. The only secure way of joining them is mechanically with a crimp, a clamp or a pinned joint. In the end, we bought ready-crimped wires from the manufacturer of the SMA alloy, complete with added steel terminal wires for soldering.

The shape memory properties of SMAs can be destroyed by overheating. This meant that we had to design our electronics carefully so that the current through the wire was limited and so that the time it was applied for was also limited.

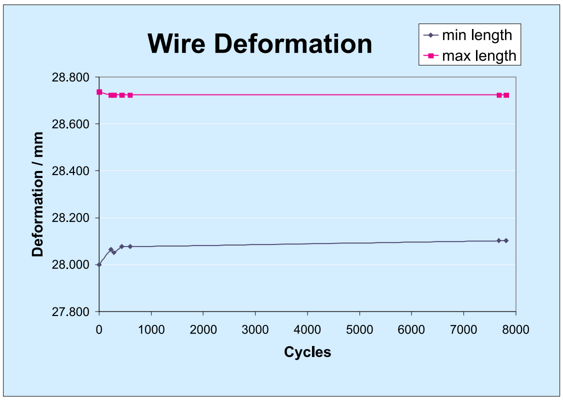


Figure 1

Medical designs

Shape memory alloys have been used in many ingenious and novel medical applications, but this simple use of a straight piece of SMA wire as an actuator illustrates many of the issues that a designer will have to consider when using these amazing materials. There is no other actuator available as powerful and compact as an SMA at present, making them a powerful part of the designer's library of solutions.

Satisfied customer: a carer with an adapted cooker.

Look here!

More clever designs from the Bath Institute of Medical Engineering: *www.bime.org.uk*

Tim Adlam is a chartered mechanical engineer, a registered clinical scientist and a design and development engineer at Bath Institute of Medical Engineering.